The microstructure approach to exchange rate theory

Exchange rate developments are often seen as the result of changes in a number of fundamental variables. In the longer term, this is a perfectly feasible view. In the short term, however, empirical analyses often show only a weak correlation between exchange rate movements and other economic indicators. One reason for this could be that exchange rates – like the prices of other assets – are largely determined by market players' expectations of how fundamental variables will develop in future. Yet these expectations are not reflected in a detailed and realistic manner in conventional exchange rate models. Furthermore, these models abstract price formation methods commonly used by market makers on foreign exchange markets. With this in mind, the following report discusses an alternative approach, in which the asset price approach is complemented by elements of microeconomic theory. The resulting microstructure model has been attracting interest among an ever greater number of exchange rate theorists for some time now and is also gaining credibility among empirical analysts.

Introduction and preliminary considerations

Most short-term exchange rate movements cannot be adequately explained by traditional exchange rate models which are based on

longer-term interaction between various fundamental variables, such as the (relative) price level, productivity, interest rates and current account balances. Again and again, a wide variety of methods has confirmed this finding as a robust empirical phenomenon in exchange rate research,[1] generally without calling longer-term links between exchange rates and fundamental data into question. Finding an explanation for short-term exchange rate movements therefore remains a challenge in both theory and practice.

Expectations play important role in price setting on foreign exchange markets

Attempting to solve this problem using the asset price approach of exchange rate theory assumes that expectations are the dominant factor on foreign exchange markets.[2] In this model, the exchange rate is the present value of discounted current and expected future fundamental variables. Under these circumstances, however, market players place much greater weight on their expectations for price setting than on prevailing values (see also the annex on pages 27-30).[3] Under this model, expectations, and therefore also exchange rates, are adjusted following the emergence of new information, but this also gives rise to problems. Empirical analyses have shown that publicly accessible news rarely accounts for more than 5% of exchange rate developments.[4]

Order flow a source of private information for market makers

Private information – in other words, information available only to a select number of market players – is therefore often seen as a driving force behind exchange rate developments. This may well include economic analyses, country analyses and the use of charting processes by professional investors. Private information resulting in revised expectations – and ultimately changes in exchange rates – aggregates on foreign exchange markets in the order flow.[5] The order flow is the balance of foreign currency purchase and sale orders submitted by customers to foreign exchange traders. It can be regarded as the pressure to buy a particular currency at any given time. In addition to long-term analyses based on fundamentals, order flow data could help explain and forecast exchange rate developments, especially in the short term.

Assumptions of asset price approach are restrictive

This different view deviates from the assumption of homogeneous and rational players who interpret new information identically and uniformly calculate an appropriate price change. It is therefore a more accurate reflection of the decentralised structure and intransparency as well as the enormous turnover of foreign exchange markets at present.

The following report therefore starts by describing the structure of the foreign exchange

1 See R Meese and K Rogoff (1983), Empirical Exchange Rate Models of the Seventies: Do They Fit Out-of-Sample?, Journal of International Economics 14, pp 3-24, and the comprehensive work of Y-W Cheung, D Chinn and A Garcia Pascual (2005), Empirical Exchange Rate Models of the Nineties: Are Any Fit to Survive?, Journal of International Money and Finance 24, pp 1150-1175.
2 See C Engel and K West (2004), Accounting for Exchange Rate Variability in Present Value Models when the Discount Factor is Near 1, American Economic Review (Papers and Proceedings) 94 (2), pp 119-125, and C Engel and K West (2005), Exchange Rates and Fundamentals, Journal of Political Economy 113 (3), pp 485-517.
3 The exchange rate is then subject to a discount factor of very close to 1.
4 See T Andersen, T Bollerslev, F Diebold and C Vega (2003), Micro Effects of Macro Announcements: Real-Time Price Discovery in Foreign Exchange, American Economic Review 93, pp 38-62.
5 For the relevance of private information on foreign exchange markets, see T Ito, R Lyons and M Melvin (1998), Is there Private Information in the FX Market? The Tokyo Experiment, Journal of Finance 53, pp 1111-1130.

market on the basis of a select number of quantitative indicators. We then go on to show how decentrally disseminated information can become part of the order flow and impact exchange rate developments. The analysis is rounded off by an econometric assessment based on a special data record.

Turnover, structures and players on foreign exchange markets

Survey by Bank for International Settlements shows marked increase in forex turnover

Turnover on the international foreign exchange markets has risen sharply over the past few years. According to the Bank for International Settlements which, together with the national central banks, twice surveyed over one thousand banks with foreign exchange operations with an interval of three years, average aggregate turnover on foreign exchange markets amounted to approximately US$3,100 billion per day in the second quarter of 2007. This is an increase of 73% over 2004. The 82% increase in foreign exchange swaps was considerably greater than the rise in spot market transactions (62%) and futures market transactions (74%), although the latter are of subordinate importance.

Interbank trade has high weighting

A breakdown of turnover by business partner shows that interbank trading is the most common form of trade, accounting for approximately 43%. Even so, its relative share has fallen slightly. With a share of 40%, bank transactions with other financial institutions (eg funds and insurance corporations) have risen sharply. The percentage of turnover attributable to the real sector of the economy, such as industrial enterprises, is currently up slightly at 17%.

Foreign exchange market turnover by instrument and counterparty

Instrument/ counterparty	2004		2007	
	US$ billion	Percentage share	US$ billion	Percentage share
Spot transactions	621	35	1,005	33
Reporting dealers	300	48	427	42
Other banks/financial institutions	213	34	394	39
Non-financial institutions	108	17	184	18
Outright forwards	208	12	362	12
Reporting dealers	73	35	96	27
Other banks/financial institutions	80	38	159	44
Non-financial institutions	56	27	107	30
Foreign exchange swaps	944	53	1,714	56
Reporting dealers	562	60	796	46
Other banks/financial institutions	293	31	682	40
Non-financial institutions	89	9	236	14
Total	1,773	100	3,081	100
Reporting dealers	936	53	1,319	43
Other banks/financial institutions	585	33	1,235	40
Non-financial institutions	252	14	527	17
Local	674	38	1,185	38
Cross-border	1,099	62	1,896	62

Source: Bank for International Settlements.

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US dollar remains dominant currency

A closer look at total turnover by currency reveals that the US dollar continues to be the dominant currency on the international foreign exchange markets, accounting for 43% of transactions (see the chart on page 20). While the US dollar, yen and pound sterling were down slightly, the proportion of total turnover attributable to the euro was largely unchanged from the last survey in 2004. By contrast, other currencies, such as the Swiss franc, the Australian dollar and the New Zealand dollar, gained in importance in terms of their respective share of total turnover.[6]

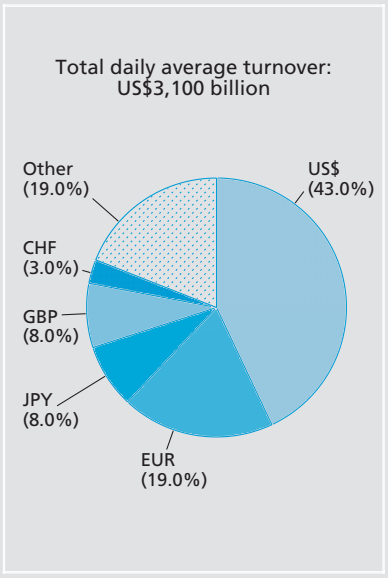
Decentralised foreign exchange trading ...

As well as high daily turnover, there are a number of major structural features which distinguish foreign exchange markets from

6 Changes in exchange rates may also have played a role in percentage shifts.

Share of foreign exchange market turnover by key currency

April 2007



Source: BIS.

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other asset markets. For instance, foreign exchange markets have a decentralised structure because ongoing foreign exchange trading – contrary to stock trading, for example – is not restricted to the stock exchange. The physically separated market participants communicate by telephone and computer in what is known as unofficial market trading. It therefore stands to reason that, in contrast to centralised asset markets, no uniform market prices can be determined for foreign exchange assets and the trading process is insufficiently transparent for market participants. Moreover, as a result of low-level regulation, foreign exchange trading is not subject to disclosure obligations. Hence, information regarding price setting as well as trading volumes and partners is generally thin on the ground. This lack of market transparency also ultimately suggests that the traditional assumption of homogeneously informed players in the exchange rate determination process could be flawed.[7]

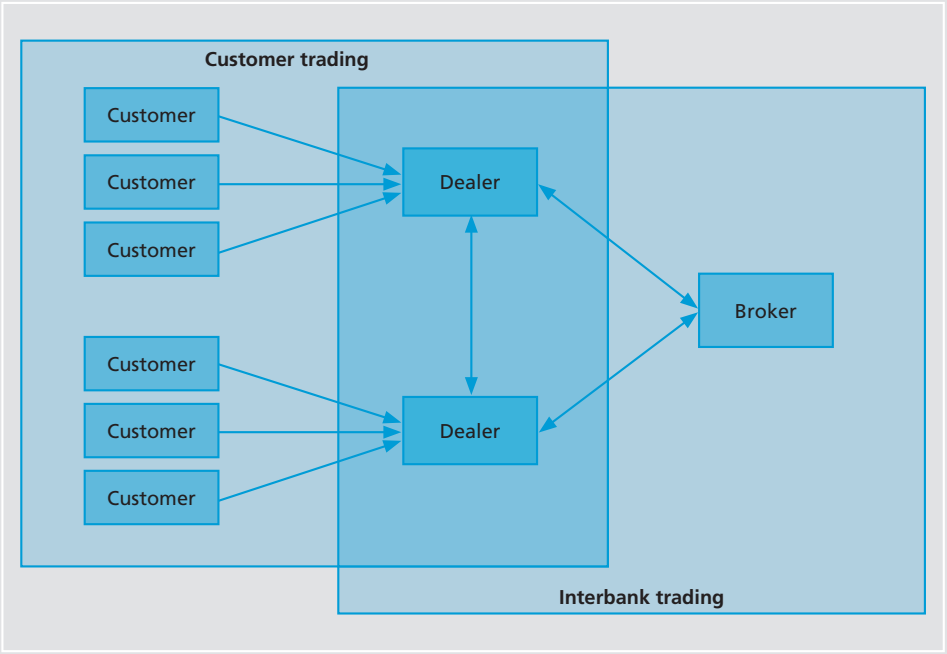
... leads to insufficient market transparency and ...

Foreign exchange market players can be divided into three groups: customers, dealers and brokers. Customers are non-banks, such as industrial enterprises, insurance companies and funds which issue foreign exchange orders to their banks which then act as intermediaries. These orders result, for example, from the execution of import and export transactions, hedging of open positions and asset and speculative transactions. The banks execute customer orders through their foreign exchange dealers, who obviously also act on behalf of the bank for risk management and proprietary trading purposes. Some banks are always willing to effect new transactions and quote buying and selling rates on request. They thus offer customers liquidity in the relevant currency on terms comparable to the centralised market. By constantly acting as a counterparty for customers' business transactions, such banks can be defined as market makers. Since the sequence of sale and purchase orders from customers cannot be influenced at the outset, market makers have to be able to control currency positions resulting from customer transactions by, for example, setting prices accordingly or making use of the interbank market.

... heterogeneously informed market participants

7 See M Sager and M Taylor (2006), Under the Microscope: The Structure of the Foreign Exchange Market, International Journal of Finance and Economics 11, pp 81-95.

Structure of foreign exchange market



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Direct interbank trade ...

Foreign exchange dealers are normally very quick to place open positions attributable to customer trade on the interbank market to mitigate portfolio risks from exchange rate developments. There are two ways of doing so: direct trading or indirect trading through a broker. Unlike dealers on the foreign exchange market, foreign exchange brokers do not take on positions of their own. They act only as a broker of foreign exchange transactions for which they receive a broker fee.

... or indirect via brokerage systems

Direct trading is conducted primarily via the Reuters Dealing 2000-1 trading system, which ensures more efficient settlement of transactions than by telephone, the previously dominant method. Indirect trading is processed chiefly by the Reuters Dealing 2000-2 brokerage system (for the pound sterling and smaller currencies) and the Electronic Broking Service (for the euro, US dollar and yen). Unlike computer-aided direct interbank trading, indirect trading participants remain anonymous until transactions are complete. Furthermore, market participants can form a picture of the prevailing market situation at any time. Electronic brokerage systems are therefore the principal instruments of communication in interbank trading. As well as anonymity and relative transparency, the segment owes its strong position to the fact that direct trading systems are often regionally based and regional foreign exchange trading is, in turn, becoming less popular.[8]

8 See D Rime (2003), New Electronic Trading Systems in Foreign Exchange Markets, in D Jones (ed), New Economy Handbook, Elsevier Amsterdam, pp 469-504.

In a two-tier process, order flow aggregates ...

The trading structure of foreign exchange markets suggests that information is aggregated in a two-tier process.[9] Firstly, market makers extract exchange-rate-related information from their customer orders. This information contains one (idiosyncratic) component that is specific to a given market maker since it represents a partial volume of the market-wide order flow and market makers cannot monitor the order flow of other foreign exchange traders. Market makers will therefore initially leave their exchange rate estimate unchanged and wait until they receive more precise information about current price pressure. This is deemed to be the case once market makers have released their positions from customer trading to the transparent interbank market and the market-wide order flow can be monitored by all. Owing to the uniform volume of information, market makers then quote more or less the same exchange rates.

... price-relevant information

Customer trade based on asymmetric information

Model assumptions: market makers' customers heterogeneously informed

Microstructure approaches to foreign exchange trading reflect the characteristics of the foreign exchange market. They are normally based on a representative market maker exposed to perfect competition when buying and selling foreign currency.[10] The market maker receives anonymous foreign exchange orders from rationally operating customers, whereby the assumption provides for one group of customers being privy to private information on the fundamental exchange rate value and a second group using only the foreign exchange market to execute or hedge primary transactions. The latter group are deemed to be uninformed customers, to put it simply. Their foreign exchange orders do not affect the exchange rate in the model but do make it more difficult for the market maker to infer information regarding the fundamental value from trade direction and order size.

As well as transaction and dealer's inventory costs, bid-ask spreads contain adverse selection costs

The models in question typically assume that demand for foreign currencies from informed customers depends on their expectations regarding the fundamental value of the exchange rate and the exchange rate quoted by the market maker (see also the annex on pages 27-30). Expectations are influenced by customers' personal analyses, ie private information. The market maker, in turn, bases his expectations of fundamental value on widely available information. Furthermore, his inventory at any given time determines his bid-ask rates. Thus, the market maker temporarily lowers both the bid and the ask rates if current inventory exceeds target inventory (and vice versa). A transaction dummy showing whether the customer is buying currency (ask) or selling currency (bid) provides for the recognition of transaction costs in the widest sense.

In addition to the usual transaction costs and the cost of inventory control, the foreign ex-

9 See R Lyons (1997), A Simultaneous Trade Model of the Foreign Exchange Hot Potato, Journal of International Economics 42, pp 275-298, and M Evans and R Lyons (2005), Understanding Order Flow, NBER Working Paper No 11748.
10 See A Madhavan and S Smidt (1991), A Bayesian Model of Intraday Specialist Pricing, Journal of Financial Economics 30, pp 99-134.

Customer trade and asymmetric information

The pricing strategy of a market maker in customer trade is empirically analysed below using transaction data of a German bank in the euro-US dollar market between October 2002 and September 2003.[1] The analysis is based on the following regression equation for the change of the bid rate or ask rate.[2]

$$\Delta s_t = \beta_0 + \beta_1 Q_t + \beta_2 I_t - \beta_3 I_{t-1} + \beta_4 D_t - \beta_5 D_{t-1} + \varepsilon_t$$

where the coefficients β_i are based on the model's structural parameters. The above equation can be estimated using the generalised method of moments while including a constant, the size of order Q_t, the dealer's inventory I_t and trade direction dummy D_t. Owing to the detailed database, it is possible to classify customers as commercial or financial. The commercial group includes commercial customers who focus on their international goods transactions and use the foreign exchange market primarily for conducting current business. In the model, it is assumed that banks, insurance companies and mutual funds which are classified as financial have an information lead over the commercial group. The table therefore contains the results of the disaggregated model with customer group dummies as well as the results of the standard model.

One thing that initially stands out is that the coefficients of both the current and the lagged inventory are statistically insignificant for the data record on which a market maker is based in this case. This can be explained by the two-step price formation process, in which the market maker passes unwanted inventory on to the interbank market instead of influencing his own currency holdings by adjusting the bid or ask rate.

When the effect of the size of the order on the bid or ask rate, and thus by implication also on the bid-ask spread is considered, the basic model initially shows a significant coefficient with the expected plus or minus sign. According to the theory of adverse selection, the market maker tends to demand higher ask rates for fairly large purchase orders. This, however, contradicts the result arranged by customer group. Commercial customers who are potentially less well informed receive bid-ask spreads that increase in line with the growth in order volume, whereas such a correlation cannot be observed in the case of financial customers who tend to be better informed. The contradiction to the theory of adverse selection also occurs if the coefficients of the trade direction dummies are analysed. On average, the bid-ask spreads paid by commercial customers (9.84 pips[3]) are ten times as large as those of financial customers (0.94 pips). In this context, the hypothesis that the market maker considers the order flow of financial customers to be uninformative can be statistically rejected. The relationship between the coefficients of current and lagged trade direction is such that, in his expectations, the market maker places an average weight of 54% on order flow information, whereas 46% goes to other available indicators. The results are comparable to those of other empirical studies, which is why the price-setting behaviour of the market maker under consideration does not differ systematically from that of other market makers.[5]

A possible explanation for the empirical results is that the customer trade does not occur anonymously, as is assumed in theoretical models. In a real situation, market makers can generally evaluate their customers quite well with regard to their category. The market maker might therefore not quote an informed financial customer any large bid-ask spreads, since this customer, with his market overview, will easily find alternative counterparties. The different knowledge levels of the customer groups about the current situation in the foreign exchange market result in market makers having various degrees of power, which – measured according to the theory of adverse selection – is reflected in counterflowing bid-ask spreads.[6]

Estimation results [4]

Item	Basic model	Customer groups	
Constant	0.21 (0.11)*		0.08 (0.11)
Size of order Q_{it}	0.34 (0.13)**	Commercial Financial	0.94 (0.17)*** 0.09 (0.09)*
Dealer's inventory I_t	– 0.01 (0.07)	Commercial Financial	– 0.04 (0.07) – 0.04 (0.07)
Lagged inventory I_{t-1}	0.001 (0.07)	Commercial Financial	0.03 (0.07) 0.05 (0.07)
Trade direction D_t	6.48 (0.20)***	Commercial Financial	9.47 (0.19)*** 2.04 (0.21)***
Lagged trade direction D_{t-1}	– 5.82 (0.18)***	Commercial Financial	– 9.84 (0.20)*** – 0.94 (0.15)***
R^2	0.23		0.34

1 See S Reitz, M Schmidt and M Taylor, End-user order flow and exchange rate dynamics, Deutsche Bundesbank Research Centre, Discussion Paper, Series 1, No 05/2007. — **2** See A Madhavan and S Smidt (1991), loc cit. — **3** A pip is defined as the smallest possible change in the exchange rate between two currencies. For example, 1 pip = US$0.0001 for the euro-dollar exchange rate and ¥0.01 for the euro-yen exchange rate. — **4** Transaction data of a German bank from October 2002 to September 2003. The dependent variable is the change in the exchange rate measured in pips between two customer orders. The instruments in the available GMM estimation are consistent with the regressors (see Bjønnes and Rime, 2005). * (**, ***) signifies statistical significance at the 10% (5%, 1%) level. — **5** See G Bjønnes and D Rime (2005), Dealer Behavior and Trading Systems in Foreign Exchange Markets, Journal of Financial Economics 75, pp 571-605 as well as C Osler, A Mende and L Menkhoff (2006), Price Discovery in Currency Markets, Brandeis University Working Paper. — **6** See R Green, B Hollifield and N Schurhoff (2007), Financial Intermediation and the Costs of Trading in an Opaque Market, Review of Financial Studies 20, pp 275-314.

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change trading model also takes into account any costs attributable to the fact that the market maker is possibly less well informed than his customers ("asymmetric information"). A customer's net demand for foreign currency is an indication of the informed content of the order and can thus be seen as a key determinant of the bid-ask spread. The market maker therefore increases the ask rate or decreases the bid rate when he receives price enquiries from new customers. The decision as to which exchange rate comes to bear is based on whether the customer is buying or selling foreign currency. This behaviour reflects the market maker's disadvantage when the information available to him is compared with that of his potentially better informed customers. The price differential increases in line with the growth in order volume because the market maker uses order volume to determine the fundamental value of the exchange rate expected by the customer. Since the market maker also receives orders from uninformed market participants, foreign exchange transactions must be seen as noisy signals of the fundamental value. Uncertainty regarding the interpretation of individual orders is greater the higher the proportion of uninformed orders and/or the lower the accuracy of private information. In practice, the market maker uses the cumulative volume of foreign currency orders – known as the order flow – to balance out the stochastic nature of orders. In doing so, the order flow itself provides the market maker with a source of private information on other participants on the foreign exchange market.

Empirical results

An empirical review of the above-mentioned price-setting patterns of a specific market maker produces mixed results (see the explanatory notes on page 23). His primary goal is obviously not to control currency stocks by adjusting ask or bid rates, as suggested in the simple model, but to correct deviations from the target inventory through the interbank market. However, empirical results show that the market maker uses the order flow as a basis for forecasting exchange rate developments. Order volume also affects the bid-ask spread, but this is not true in all cases. A breakdown by customer group shows that potentially better informed customers with increasing order sizes are not offered higher bid-ask spreads. It can be presumed that, in the event of price discrepancies, these business partners – contrary to the model described – can easily find alternative business partners based on their market knowledge. The market maker is therefore unable to pass on the cost of his information deficit to them to remain competitive.

Interbank trading and exchange rate development

Order flow as leading indicator

Despite the discrepancies between the theoretical model and empirical results, the price-setting patterns of the market maker show that, on intransparent markets with heterogeneously informed market participants, order flow mirrors private information and estimates of the fundamental exchange rate value. While, as already mentioned, a market maker's order flow is not to be seen as a clear signal of fundamental value, exchange rate

orders from customers do ultimately reflect the value of current and anticipated fundamental variables. Whether or not individual customers actually identify the information relating to their orders is irrelevant. The order flow contains information on the current and anticipated state of the economy which is not available in any other form at that time since the relevant data have not yet been published. Thus, it could prove to be a good leading indicator.

Owing to the partly idiosyncratic nature of the individual order flow – a market maker only ever receives a proportion of customer orders on the market – prices are not adjusted directly; only the bid-ask spread is adjusted. After all, there is the danger that a significantly different rate from another market marker will be used for arbitrage. Exchange rate developments therefore usually only become apparent once all market makers have released their net positions from customer trading to the transparent interbank market and the market-wide order flow can be seen by all.

Order flow plays significant explanatory role in exchange rate regression

Even then, market makers are not aware of the current fundamental value upon which the exchange rate is based owing to the usual delay in publication of economic data. It can be assumed, however, that the aggregated order flow is factored into market makers' expectations and therefore also reflected in market price developments (see the annex on pages 27-30). This also applies when expectations are a key factor in determining the exchange rate. Moreover, the concurrent order flow from interbank trading obviously plays a significant explanatory role in day-to-day exchange rate developments.[11]

Predictive power of order flow generally limited

The high contemporaneous correlation between exchange rate and order flow may suggest that the latter can be used to forecast exchange rate developments. However, it can be shown, on the one hand, that regressing exchange rate changes on delayed order flow variables result in determination coefficients of approximately zero and, on the other, that Granger causality relationships tend to flow from exchange rate to order flow.[12] The overall predictive power of order flow is clearly very low in interbank trading; by contrast, the order flow of major market makers might have potential predictive power in the customer trading segment. This assessment is supported by the fact that, owing to the prevalence of asymmetric information in the customer trading segment and the more or less continuous distribution of customer orders over the given period, information relevant to exchange rates is aggregated slowly in the individual order flow – in contrast to what happens in the interbank trading segment. Delays of this kind form the very basis for potentially successful forecasting. Another study actually proved that the predictive quality of the customer trading order flow of a major US bank between 1993 to 1999 improved for forecast periods of at least two to four weeks.[13] For shorter periods, by contrast, the order flow does not

11 See M Evans and R Lyons (2002), Order Flow and Exchange Rate Dynamics, Journal of Political Economy 110, pp 170-180.
12 See M Sager and M Taylor (2005), Order Flow and Exchange Rate Movements, University of Warwick Working Paper.
13 See M Evans and R Lyons (2005), loc cit.

produce more reliable results than the naive random walk forecast.[14]

Concluding remarks

The microstructure approach to exchange rate theory builds on the traditional asset price approach by taking into account, on the one hand, the realistic dominance of player heterogeneity on the foreign exchange market and, on the other, asymmetric information structures. This gives rise to a two-tier process in which macroeconomic information is collected through the order flow of market makers and subsequently incorporated into the exchange rate. The first stage of this model sees market makers accepting orders from customers who may – knowingly or unknowingly – be better informed of fundamental variables affecting exchange rate development. In interbank trading, the market makers then pass on their balances from customer purchase and sale orders. Generally, interbank trading, unlike customer trading, is set to become considerably more transparent thanks to electronic trading platforms, hence the setting of comparable prices by market makers based on the prevailing market-wide order flow in the model in question.

Factoring the order flow into the equation does actually constitute a considerable improvement in the regression quality of higher-frequency exchange rates over the news approach. This is because, using the microstructure approach, order flow acts as a leading indicator, aggregating information on fundamental data long before they are published. During the market process explained above, information is continuously factored into the exchange rate price and therefore comes as no surprise when the economic data are published. Furthermore, empirical studies show that the correlation between order flow and exchange rate in interbank trading is very strong on a contemporaneous basis only, while order flow in customer trading gives a noisy signal of the market-wide order flow. From the perspective of the average market maker, order flow therefore seems to be useful for predicting exchange rates to a limited extent only.

14 The described success of the order flow in predicting exchange rates is substantiated by the contributions of T Ito and Y Hashimoto (2006), Price Impacts of Deals and Predictability of Exchange Rate Movements, NBER Working Paper 12682, and S Reitz, M Schmidt and M Taylor (2007), loc cit.

Annex

The asset price approach of exchange rate theory

In the asset price approach of exchange rate theory, the exchange rate s_t can be represented as a weighted average of its fundamental value f_t and the exchange rate expected for the next period.

$$s_t = (1 - b)E_t f_t + bE_t s_{t+1} \quad (1)$$

In this case, b stands for the discount factor and E_t signifies the expected value on the basis of the information available at a point in time t. The expression $E_t f_t$ takes due account of the fact that, in the real world, it is also not possible to observe the current condition of the fundamental value. Depending on which macroeconomic variables the calculation of f_t and b is based, the exchange rate can be modelled in different ways, for example, using the monetary approach. If equation (1) is iterated forwards, this results in the usual notation of the asset price approach.

$$s_t = (1 - b) \sum_{i=0}^{\infty} b^i E_t f_{t+i} \quad (1a)$$

In this notation, the exchange rate is to be construed as the present value of current and expected future conditions of the fundamental variables. If, instead, rates of change are considered, it becomes clear from where possible problems with the forecast of exchange rates on the basis of fundamental data could originate.

$$\Delta s_{t+1} = \frac{1-b}{b}(s_t - E_t f_t) + \epsilon_{t+1}, \text{ where} \quad (2)$$

$$\epsilon_{t+1} = (1 - b) \sum_{i=0}^{\infty} b^i (E_{t+1} - E_t) f_{t+1+i} \quad (3)$$

The exchange rate change is thus determined by a systematic and an unsystematic component. According to equation (2), the systematic component implies that the exchange rate rises when it is above its current fundamental value and vice versa. The reason for this is that, in the case of rational expectations, expected future fundamental values are included at a discounted rate in the exchange rate. Therefore, if the current exchange rate is above its fundamental value, this merely reflects the expectation of market participants that the fundamental value will rise in future. The exchange rate change and the adjustment of expectations offset each other again in the following periods, thereby ensuring stability. The second part is specified in more detail by equation (3) and represents the unsystematic component as the sum of all revisions of expectations that are triggered by new information available to all market participants.

Empirical studies now regularly show that the macroeconomic variables themselves on which the fundamental value of the exchange rate is based tend to exhibit only weak mean reversion over the long term. Evidently, the bulk of the changes in the fundamental value – technological progress, for example – are of a permanent nature. If the systematic component is therefore negligible and new information dominates their development over time, market participants will think that the probability of a rise in the fundamental value is just as high as a fall. The current value is therefore the best forecast of all future fundamental values. On the basis of equation (1a), the exchange rate then corresponds to its current fundamental value, $s_t = E_t f_t$, and follows a random walk. Therefore, if, owing to permanent changes in the macroeconomic variables which usually dominate in the real

world, the exchange rate cannot be predicted, this by no means signifies that its development should be seen as completely separate from the fundamental value. Predictability is therefore no necessary condition for the validity of theoretical exchange rate models.

In the literature, however, it is pointed out that, although the development of the fundamental variables over time is the result of predominantly permanent shocks, the fundamental variables do not necessarily follow a random walk.[15] In this case, they are often modelled as follows.

$$\Delta f_t = \phi \Delta f_{t-1} + u_t, \text{ where } 1 > \phi > 0 \qquad (4)$$

For the sake of simplicity, it was assumed here that the market participants have complete information about the current state of the fundamental variables. Under these circumstances, the present value formula (1a) implies a systematic component in the development over time of the exchange rate's deviation from its fundamental value, thus resulting in the following equations.

$$s_t - f_t = \phi\,(s_{t-1} - f_{t-1}) + \frac{\phi b}{1-\phi b} u_t \text{ and } \epsilon_{t+1} = \frac{\phi b}{1-\phi b} u_{t+1}$$

This should initially result in a potential for explaining and forecasting the exchange rate. However, with the strong weighting of the expected future development of the fundamental variables for price formation, which is common in foreign exchange markets, the discount factor b will be close to 1 when using daily data. In this case, the explanatory power for econometric models of the exchange rate will remain low. If the theoretical coefficient of determination

$$R^2 = \frac{(1-b)^2 \phi^2}{(1-b)^2 \phi^2 + (1-\phi^2)}$$

is calculated in order to illustrate equation (2), values of $b > 0.95$ and $\phi < 0.8$, for example, result in an explanatory share of the systematic component of less than 1% in the variance of the exchange rate. The problem of the weak empirical relationship is accentuated by the fact that the econometrist has no real-time data at his disposal. Even if the "true" exchange rate model were available, the structural coefficients estimated on the basis of the available ex post data would differ from those based on real-time data. This causes the coefficient of determination to further decline.[16]

Even if the short-term exchange rate analysis on the basis of the traditional asset price approach is therefore limited, this does not mean that exchange rates cannot be explained or predicted in general. In practice, as well as in the academic literature, a class of exchange rate models, which are based on the revisions of expectations, ie the second component in equation (2), has established itself since the 1990s. In cases where macro models make no statement whatsoever about how new information is reflected in exchange rate changes, microstructure approaches try to take account of the institutional factors in the exchange rate markets by moving away from the assumption of homogeneously informed market participants.

The microstructure approach of exchange rate theory

There are two important elements in the microstructure approach of exchange rate theory: the market maker's price quotations to his customers and the revisions of expectations owing to the

15 See C Engel and K West (2004), loc cit.
16 See M Evans (2005), Where Are We Now? Real-Time Estimate of the Macro Economy, International Journal of Central Banking 1, pp 127-175.

market-wide order flow, which are ultimately reflected in changes in the exchange rate.

Description of customer trade

This is based on a representative market maker, who tries to evaluate the orders of informed customers to draw inferences on the fundamental factors driving the exchange rate. In this approach, a purchase order of an informed customer j at point in time t for quantity Q_{jt} of foreign currency is formulated as a linear function of the difference between the expected value of fundamental value μ_{jt} based on his own information and the rate s_{it} quoted by market maker i as well as an unsystematic liquidity component L_{jt} that is inelastic to the exchange rate.

$$Q_{jt} = \theta(\mu_{jt} - s_{it}) + L_{jt} \tag{5}$$

The market maker bases his expectations of fundamental value μ_{jt} on publicly available information. In order to determine his bid or ask rate, an inventory variable and a cost variable are added to the expected value.

$$s_{it} = \mu_{it} - \alpha(l_{it} - l^{*}_{it}) + \gamma\, D_t \tag{6}$$

The market maker then lowers the bid rate and the ask rate once the current foreign exchange holdings l_{it} exceed the desired inventory l^{*}_{it}. A transaction dummy D_t, showing whether the customer is buying (ask) or selling (bid) currency provides for the recognition of transaction costs of γ per unit of foreign currency.

Interbank trading and exchange rate development

The following equations are again based on exchange rate equation (2), in order to illustrate the exchange rate's reaction to the market-wide order flow.[17]

$$\Delta s_{t+1} = \tfrac{1-b}{b}(s_t - E^{m}_{t} f_t) + \epsilon^{m}_{t+1} \tag{7}$$

$$\epsilon^{m}_{t+1} = (1-b)\sum_{i=0}^{\infty} b^{i}(E^{m}_{t+1} - E^{m}_{t}) f_{t+1+i} \tag{8}$$

In contrast to the traditional asset price approach, the microstructure approach of the exchange rate focuses on the market makers' expectations or expectation revisions. Since the order flow is based on transactions of internationally active economic agents and may, as the leading indicator, constitute an early signal of the fundamental data – long before their official publication – the process of the fundamental value in equation (4) must be supplemented as follows.

$$\Delta f_t = \phi \Delta f_{t-1} + u_t + \delta \upsilon_t \tag{9a}$$

and

$$x_t = \lambda x_{t-1} + \upsilon_t \tag{9b}$$

Here, x_t signifies the aggregated order flow between t and t+1 for all market makers. In contrast to the observable shocks u_t, the variable υ_t represents the initially unknown part of the fundamental value innovation which can be observed only with a time lag. The market makers therefore do not know the current fundamental value, which is why the expectation error is $f_t - E^{m}_{t} f_t = \delta \upsilon_t$. However, the expectation error is correlated with the

17 See M Evans and R Lyons (2005), Meese-Rogoff Redux: Micro-Based Exchange-Rate Forecasting, American Economic Review Papers and Proceedings 95, pp 405-414.

current order flow,[18] a fact which is taken into account in the market makers' expectations and therefore also reflected in market price changes.

$$\Delta s_{t+1} = \frac{1-b}{b}(s_t - E_t^m f_t) + \frac{1}{1-b\phi} u_{t+1} +$$

$$\frac{(1+\phi(1-b))\delta}{1-b\phi}(x_t - \lambda x_{t-1}) \qquad (10)$$

The modified exchange rate equation shows that the unexpected part of the market-wide order flow $x_t - \lambda x_{t-1}$ also significantly influences the exchange rate whenever the discount factor is close to 1: the coefficient that measures the exchange rate's reaction to an unexpected change in the order flow then converges to $\delta/(1-\phi)$. The coefficient thus becomes greater the more strongly the order flow correlates with the unobservable part of the fundamental value innovation and the more strongly the fundamental value changes are autocorrelated. In actual fact, an empirical study by Evans and Lyons shows that the current order flow from interbank trading makes a significant contribution to the explanation of daily changes in the exchange rate.[19] After the order flow variables are applied, the regressions show determination coefficients of 0.64 for the DM-dollar exchange rate and of 0.45 for the yen-dollar exchange rate, whereas these were negligible earlier.

18 The effect of the correlation between expectation error and order flow is that the order flow is generally also suitable for forecasting the fundamental data which are published with a time lag. Empirical evidence for this is given in M Evans and R Lyons (2004), Exchange Rate Fundamentals and Order Flow, Mimeo, Georgetown University.

19 See M Evans and R Lyons (2002), Order Flow and Exchange Rate Dynamics, Journal of Political Economy 110, pp 170-180.